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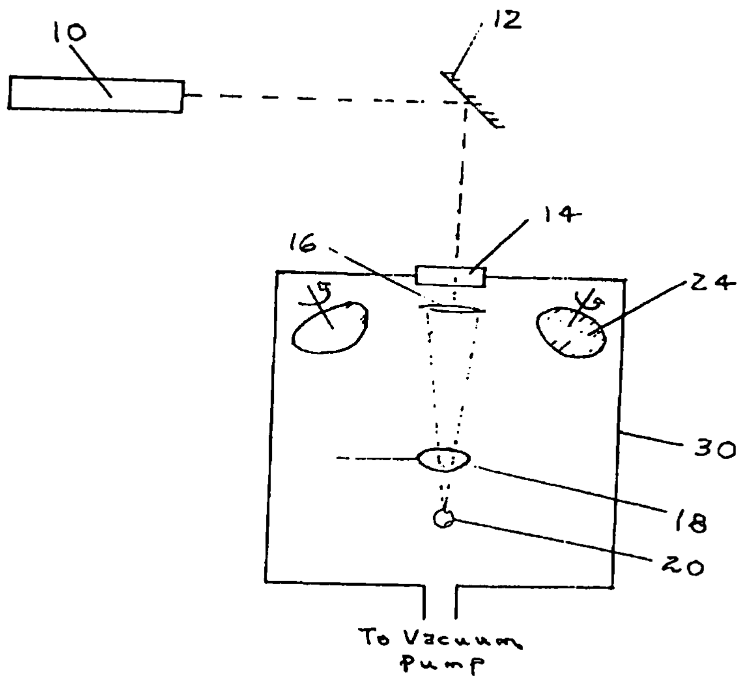
(57) Abstract

A beam from laser (10) is reflected by a mirror (12) to pass through window (14) in the wall of vacuum chamber (30). Optical components to be coated with a diamond-like carbon coatings are attached to holders (24) so as to be directly within the plume of high energy carbon ions displaced from graphite target (12) of the vacuum chamber.



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DIAMOND COATED COPPER OPTICS

This invention relates to high-power laser optics. More particularly, apparatus and method are provided for reflecting laser beams which may be used in material processing or other applications.

High-power carbon dioxide lasers for material processing and other applications have become widely used in recent years. It is desirable to focus the energy from such lasers to maximize effectiveness of cutting, drilling or other material processing applications. It is also desirable to be able to move the laser beam along the material being processed. The usual means of focusing lower-energy laser beams is by lenses made of zinc selenide or zinc sulphide, but the absorption of energy by these materials prevents their use with high-power lasers.

To overcome the limitations of transmitting optics for focusing, reflecting optics in the form of parabolic mirrors have been developed. Flat mirrors or other shapes of mirrors may also be used for directing a laser beam or moving the beam to a selected location. It has been found that copper is a suitable material to fabricate such mirrors, although other metallic materials can be used. Copper is easy to machine and polish and the high thermal conductivity of copper is an advantage in high-power laser applications, where the mirrors must be liquid-cooled. However, copper is a very soft material and it is easily damaged. The production environment in which the mirrors operate may contain fumes, humidity and, in some applications, molten particles from the material being processed. This environment can be very damaging to uncoated mirrors. In addition, as copper increases in temperature, it becomes prone to oxidation and loses its reflectivity. A protective coating on copper or any other metal used in such mirrors is needed.

A coating of molybdenum is presently used to increase the life of copper mirrors. The typical molybdenum coating protects copper from most of the damaging factors, but molybdenum coatings, in the thicknesses usually employed, absorb more than 2.5% of the laser power. For high-power lasers, having power outputs greater than 10 kilowatt, for example, the total power loss at the mirror is in the hundreds of watts.

Diamond has been suggested as a protective coating for copper mirrors. Diamond is an ideal material for coatings on mirrors to be used with high-power carbon dioxide lasers because it has low absorption of electromagnetic waves at a wavelength of 10.6 microns, the wavelength of energy from a carbon dioxide laser. Attempts have been made to coat such mirrors with diamond, the diamond being deposited by chemical vapor deposition, but adherence of the coating to the mirror has not been satisfactory.

U.S. Patent 4,987,007 describes a process for depositing a diamond-like coating on solids. This process of coating employs a very high energy laser beam which is focused on a graphite target to cause ablation of carbon from the target. The high-energy carbon ions from the plume of ablated carbon are deposited on a substrate to form the coating or film. The resulting coating has many bonds corresponding to the atomic bonds in diamond, along with other material which is not crystalline. Such material is often called "diamond-like carbon." Coatings of such material are provided by SI Diamond Technology, Inc. of Houston, Texas as "AMORPHIC DIAMOND."

There is a need for an improved coating for copper or other metallic optical apparatus to provide protection for a reflecting surface against physical or chemical damage in the environment in which it is used. Such coating should adhere to the surface under conditions of use with very high-power lasers, and the coated mirror should reflect a very high percentage of incident energy.

According to one embodiment of the present invention, there is provided an improved mirror of metallic material for laser applications wherein the improvement comprises a coating of diamond-like carbon on the reflecting surface of the mirror. In a preferred embodiment, the mirror is made of copper.

According to another embodiment of the present invention, there is provided an improved method for focusing and directing a laser beam wherein the improvement comprises focusing and directing the laser beam by a mirror, the reflecting surface of the mirror having a coating of diamond-like carbon.

Fig. 1 is a sketch of apparatus which may be used to form a coating of diamond-like carbon on metal mirrors.

Referring to Fig. 1, a schematic of apparatus used to deposit the coating of this invention is shown. Such apparatus is generally described in U.S. Patent 4,987,007, which is incorporated herein by reference for all purposes. The beam from laser 10 is reflected by mirror 12 to pass through window 14 in the wall of vacuum chamber 30. The beam then passes through lens 16 where it is focused on graphite target 20. Ring electrode 18 may be used to draw ions from the plume formed by the concentrated laser energy impinging on target 20. Optical components to be coated with the coating of this invention are attached to rotating substrate holders 24 so as to be directly within the plume of high energy carbon ions displaced from graphite target 12. Substrate holders 24 are preferably within a solid angle of about 60° as measured perpendicular to target 20, so as to be sufficiently within the plume. Preferably, substrate holders 24 are rotated during deposition of a coating.

A high-power Q-switched Nd:YAG laser may be used. The power of laser 10, focused by lens 16, should produce a power density on graphite target 20 of at least 10^7 watts per square centimeter. Preferably, the power density is greater than 10^{10} watts per square centimeter on the graphite surface. Pressure in the vacuum chamber 30 is reduced by vacuum pumps to less than about 10^{-5} torr, and preferably is in the range of about 10^{-7} torr. Ring electrode 18 is preferably biased at a voltage in the range from about -1 kilovolt to about -4 kilovolts, but is more preferably biased in the range from about -2 kilovolts to about -3.5 kilovolts.

Substrate holders 24 may be electrically biased or not biased, but preferably it is biased by pulsed RF voltage which is synchronized with the laser pulses. The voltage may be greater than -100 volts, but is preferably in the range of -200 to -300 volts.

The time of deposition is varied to produce films of suitable thickness. Preferably, the film thickness is in the range from 0.25 to about 0.5 microns, but films having any desired thickness up to several microns may be used.

After coating, the coated mirror is removed from vacuum chamber 30 and used in apparatus requiring reflection of high-energy laser beams.

The mirrors of the present invention may generally be any that are utilized to reflect laser beams. Some embodiments of this invention will be particularly useful in

the practice of machining or processing of materials by high-power lasers. The mirrors may be made of copper, aluminum, stainless steel or other metals or alloys. When parabolic mirrors are used, the focal point of the mirror is selected to provide a concentrated beam of energy at the desired location, such as at the location where drilling or cutting of material is to be performed.

Copper mirrors are available from II-VI, Inc. of Saxonburg, Pennsylvania. Machining or cutting apparatus employing high-power laser energy is available from many sources in industry. The coated mirrors of the present invention may be utilized in apparatus for cutting or materials processing or may be used in any other apparatus in which laser energy is to be reflected and where the lifetime of the reflecting surface is of importance.

A diamond-like coating of the present invention may be applied by any method that will produce such coating. The term "diamond-like carbon" generally includes carbon materials having both amorphous and microcrystalline atomic structures and having a hydrogen concentration from about 0% to about 40%. A preferred form of diamond-like carbon is "AMORPHIC DIAMOND," produced by the method of U.S. Patent No. 4,987,007 and available from SI Diamond Technology, Inc. of Houston, Texas.

The absorption of energy of such materials is less in the range of wave-lengths from about 8 microns to about 14 microns than at wave-lengths outside this range. Diamond-like coatings will be particularly useful on mirrors used to reflect energy in this band of wave-length.

Example 1

A one-inch diameter copper mirror was obtained from Laser Power Optics of San Diego, California. The mirror was placed in a vacuum chamber such as chamber 30 of Fig. 1. Pressure in the chamber was reduced to about 10^{-7} torr. Laser power was concentrated on a graphite target to produce an energy density or about 10^{10} watts per square centimeter. A ring electrode such as electrode 18 was biased to -2.8 kilovolts. A rotating substrate holder such as 24 was biased with RF pulses synchronized with the

laser pulses at a voltage of -250 volts. A coating having a thickness in the range from 0.25 to 0.5 microns was formed.

The coated mirror was removed from the vacuum chamber and standard tests, prescribed in MIL-C-48497, were performed to determine the durability of the coating.

For adhesion testing, the adhesive surface of a one-inch wide cellophane tape was firmly pressed against the coated surface and quickly removed at an angle normal to the coated surface. There were no effects of the tape on the coating surface.

A humidity test was performed by placing the mirror in an environmentally controlled chamber for 24 hours at a temperature of 120°F. and a relative humidity from 95 to 100%. There were no visible effects on the coating after the test.

Moderate and severe abrasion tests were performed on the mirror. In the moderate test a clean, dry laundered cheese cloth, ¼-inch thick and 3/8-inch wide, was rubbed across the surface for at least 50 times with one pound of bearing force. In the severe abrasion test a standard eraser was rubbed 20 times on the coated surface with a bearing force of 2.5 pounds. Neither test produced any visible effect on the coating.

A salt fog test was performed by immersing the coated optical component for 24 hours in a solution of sodium chloride containing 6 ounces of salt in 1 gallon of water. Subsequent to this test the coated optical component was removed from the solution and dried with clean, laundered cheesecloth and then evaluated for performance. There was no visible effect on the coating.

Absorption of the laser beam from a carbon dioxide laser was measured using the "gradient method," prescribed by the International Standards Organization as No. ISO/TC-172-SC 9/WG 6. In this method, the rates of change in temperature of the mirror and holder assembly during irradiation of the mirror with a laser and during the period after the laser power is turned off are measured. Use of a procedure having both heating and cooling phases eliminates or minimizes the error due to losses from convection and thermal conduction. The following formula was used for calculating absorptance of energy:

$$\text{Absorptance} = \frac{\Sigma m_i c_i}{P}\left[\Delta T/\Delta t \text{ heating phase} + \Delta T/\Delta t \text{ cooling phase}\right]$$

where, m is mass, c is specific heat (summed over all materials, i, present), P is power, T is temperature and t is time.

The coated copper mirror was exposed to radiation from a 1.2 kilowatt carbon dioxide laser for one minute. Longer exposure was not possible because the mirror was not water cooled. The test showed 1.6% absorption on reflection of the laser beam, both before and after the environmental tests outlined above. Similar tests using molybdenum coated copper mirrors showed 2.5% absorption of the energy.

It will be appreciated that while the present invention has been primarily described with regard to the foregoing embodiments, it should be understood that variations or modifications may be made in the embodiments described herein without departing from the broad inventive concept disclosed above or claimed hereafter.

CLAIMS

What is claimed is:

1. A mirror for reflecting a laser beam, comprising:
a metallic reflecting surface adapted to reflect the beam; and
a coating on the surface, the coating comprising diamond-like carbon.

2. The coating of claim 1 wherein the coating thickness is in the range from 0.25 microns to about 0.5 microns.

3. The coating of claim 1 wherein the coating is formed by laser ablation of carbon from a target in a vacuum chamber, wherein the laser energy on the target is at least 10^7 watts per square centimeter.

4. The mirror of claim 1 wherein the metallic reflecting surface is made of copper.

5. A method of reflecting a laser beam comprising the steps of:
providing a metallic mirror adapted to reflect the beam, the mirror having a coating of diamond-like carbon.

6. The method of claim 5 wherein the mirror is made of copper.

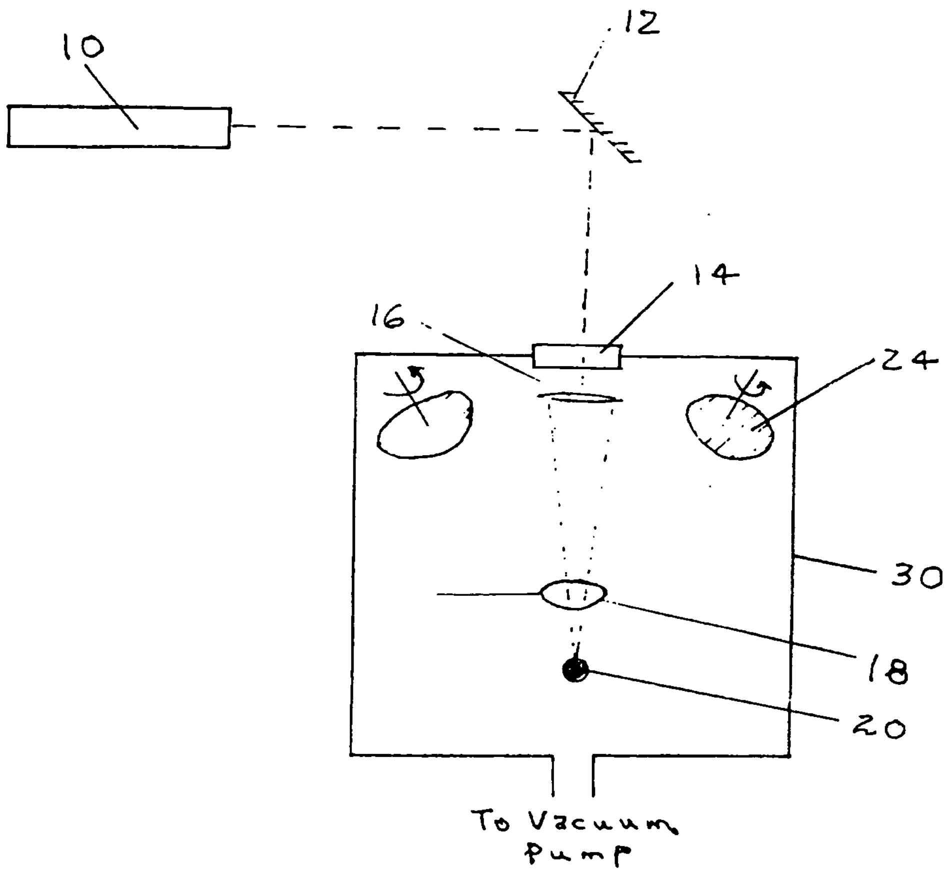

Fig 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/01129

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : B32B 17/06; G02B 5/08; 305D 1/8
US CL : 359/883, 884; 428/216, 336, 412
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/883, 884; 428/216, 336, 412

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	E. Science Publishers B.V. issued 1991, S. Scaglione et al, "Study of a-C:H Material as Protective Coating for CO Laser Copper Mirrors", pages 777-782.	1-6
Y	US, A, 5,268,217 (KIMOCK ET AL) 07 DECEMBER 1993, figs. 1-4.	1-6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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